P-23: Neutron Science and Technology

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Introduction

The Neutron Science and Technology Group (P-23) carries out a wide-ranging program of fundamental and applied research in weapons physics, nuclear physics, and quantum-information science. The common feature of this diverse set of efforts is the application of state-of-the-art techniques in particle and light detection and the recording of transient events.

Within the arena of weapons physics, we contribute to Laboratory programs in stockpile stewardship (SS) by participating in the design and fielding of subcritical experiments (SCEs), hydrodynamic experiments, and the reanalysis and archiving of data from past nuclear-weapons tests. Our fundamental research focuses on nuclear and weak-interaction physics and on state-of-the-art measurements of astrophysical phenomena such as solar neutrinos and ultra-high-energy gamma rays. Applied research includes the development of quantum-information technologies, such as quantum computation and encryption, the application of imaging and neutron technologies to problems relevant to national defense and industry, and participation in the accelerator production of tritium (APT).

We conduct our research at local facilities such as the Los Alamos Neutron Scattering Center (LANSCE), Milagro (see Figure 1), and local high-explosive firing sites, as well as at remote facilities like the Nevada Test Site (NTS), the Sudbury Neutrino Observatory (SNO), Fermilab, and Brookhaven National Laboratory. All of these facilities are world class, offering the best available resources for our research. Of these facilities, only the Milagro gamma ray observatory is owned and operated by P-23.

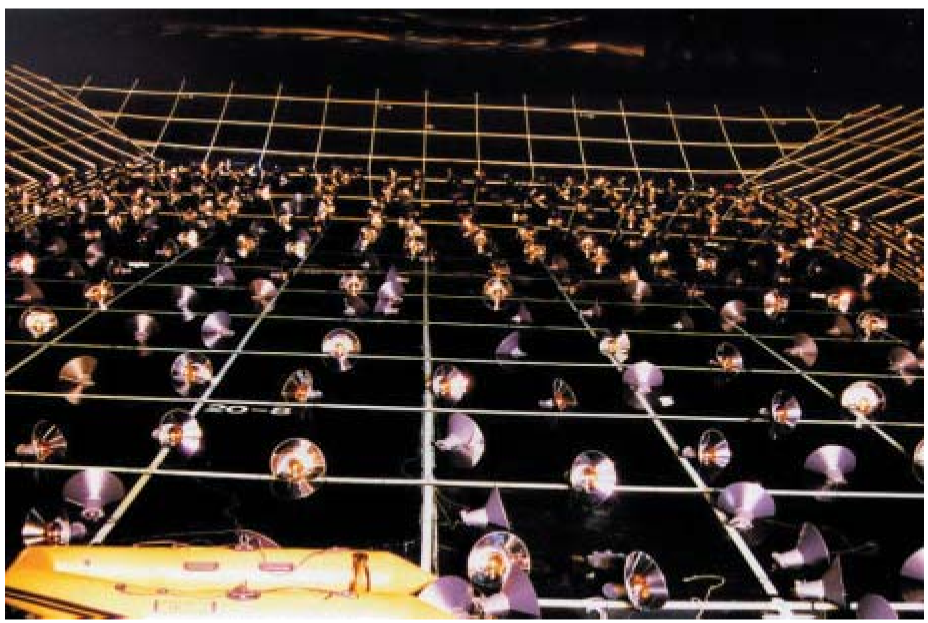


Figure 1. The Milagro detector is comprised of 723 photomultiplier tubes situated in a 5,000-m^2, 8-m-deep pond at an altitude of 8,700 ft. The photograph shows the pond before it has been filled with water, which will allow the Kevlar-bound photomultiplier tubes to extend towards the sky. Milagro has detected the particle showers produced by very high-energy gamma rays as they enter the atmosphere.

Weapons Physics and Stockpile Stewardship

With the end of nuclear testing, SS has become the foundation of the Los Alamos nuclear-weapons program. Our knowledge of how nuclear weapon systems perform relies on data obtained from tests at the NTS and test locations in the Pacific Ocean. Preserving, analyzing, and documenting NTS weapons test data is crucial to the success of SS. P-23 shares responsibility for preservation and reanalysis of these data with other groups involved in these tests. In P-23, physicists and engineers who performed the original measurements are working to reanalyze and correlate the data derived from different events. In addition, new scientists, with no previous test experience, are learning the techniques of making such measurements in case the need should arise for future underground tests.

The work of the group concentrates on analysis of Pinhole Neutron Experiments (PINEX) imaging data and on neutron emission measurements from Neutron Experiments (NUEX) and Thresholded Experiments (THREX). New methodologies using improved analytical techniques are being applied. These data complement the reaction-history and radiochemical measurements made by other groups. As a whole, this research has provided a better understanding of the underlying physical processes, and the comparison of results from different tests has allowed us to systematically study the behavior of nuclear explosives.

To ensure the success of SS in enabling us to certify the performance of our nuclear weapons in the absence of nuclear testing, P-23 is striving to develop better physics models that can be incorporated into computer codes to calculate explosive performance. Providing the community with rigorously analyzed and certified NTS data will allow the validation of the new Accelerated Strategic Computing Initiative (ASCI) codes thereby enabling the design community to address with confidence the issues of aging and remanufacture of our stockpile weapons.

In addition to the reanalysis of historic NTS data, P-23 is participating in a series of experiments to explore weapons physics issues of a more microscopic nature. In these experiments, we use chemical explosives and gas guns to create the pressures and velocities relevant to weapons physics regimes and examine issues such as the equation of state of shocked materials, formation and transport of ejecta from shocked surfaces, and growth of hydrodynamic instabilities. Our work includes a series of underground SCEs involving plutonium at the U1a facility at the NTS. These experiments employ a wide range of technologies, including gated visible imaging, gated x-ray imaging, holography, and infrared temperature measurement, to explore the physical phenomena. P-23 is currently developing two new technologies: fast infrared imaging technology, which will provide the ability to study freeze-frame dynamic motion in the infrared range, and ellipsometry to understand the dynamic emissivity of shocked matter. The data from these experiments will permit a better understanding of the hydrodynamics of interest to the weapons program and will allow us to benchmark developing models for the ASCI program.

Other weapons program work focuses on the phenomenology of weapons performance as components age. Nuclear tests and other previous weapons experiments did not address this issue, and the data from these tests are not sufficient to assure the safety and reliability of the nuclear-weapons stockpile without nuclear testing. The SS program is intended to provide a scientific basis for addressing this and other assurance issues without nuclear testing. As part of this effort, we have joined colleagues in other groups and divisions at Los Alamos National Laboratory, as well as from the Lawrence Livermore National Laboratory, to study the following issues:

- the performance of chemical explosives, including changes in performance as they age;
- the fundamental physics of plutonium and surrogate materials; and
- the characteristics of materials undergoing shock.

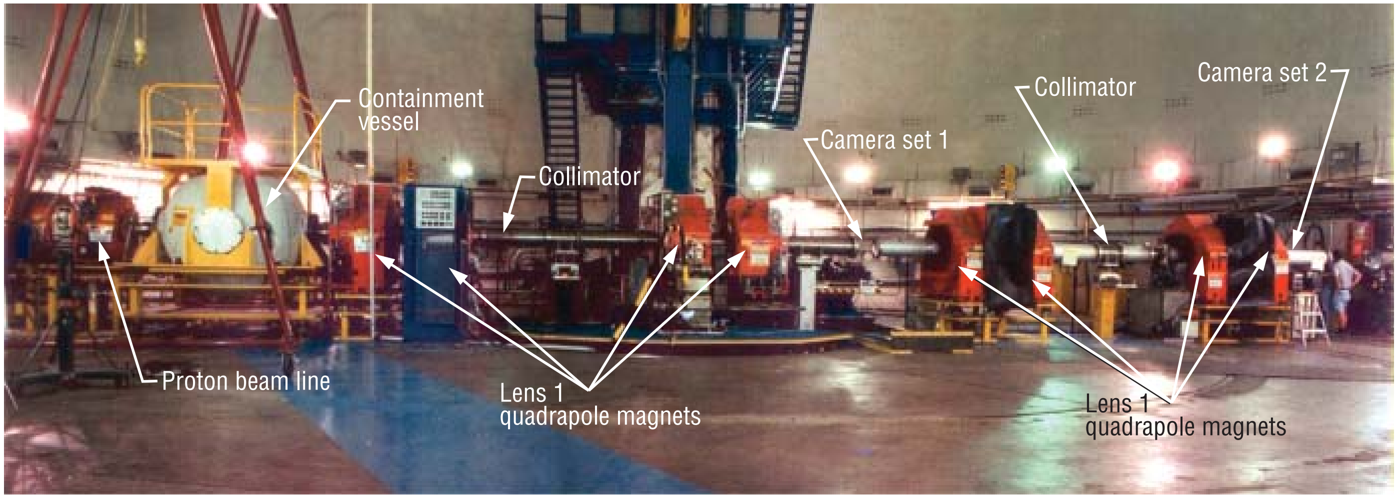
For these studies we use neutrons and protons from LANSCE sources, including protons directly from the linear accelerator, moderated neutrons from the Manual Lujan, Jr., Neutron Scattering Center (MLNSC), moderated neutrons with tailored time-structure from the Weapons Neutron Research (WNR) Blue Room, and unmoderated neutrons from the WNR fast-neutron source.

Neutron resonance spectroscopy (NRS) is a technique that uses Doppler-broadened neutron resonances to measure internal temperatures in dynamically loaded samples. In 1999–2000, P-23 worked with LANSCE operations to obtain an order of magnitude more neutrons than is possible using the MLNSC production target, thereby enhancing the utility and accuracy of the technique. In addition to temperature measurements, P-23 carried out preliminary measurements for future experiments that will measure the temperatures attained at frictional interfaces and in the "dead zones" of detonated chemical explosives. Finally, on a beam line at the MLNSC production target, we performed a series of static measurements that demonstrate that NRS can provide important information about the detailed distribution of individual constituents of uranium-niobium alloys (see the detailed research highlight "Neutron Resonance Spectroscopy: The Application of Neutron Physics to Shock and Material Physics" in Chapter 2).

An important element of the SS program at LANSCE is proton radiography (P-RAD). P-23 is working as part of the radiography project by developing and fielding imaging systems and advanced detector systems (see Figure 2). The charge coupled device (CCD)-based camera system with fast gating developed by P-23 over the report period is now capable of producing 16 high-quality time-separated images. The group has also collaborated with the Subatomic Physics Group (P-25) in the development of a pixilated, gas-amplification wire-chamber detector for proton radiography. The group continues to work with Applied Physics (X), Dynamic Experimentation (DX), and Atomic Weapons Establishment (United Kingdom) colleagues to design and optimize P-RAD experiments that are relevant to SS in a variety of weapons-physics areas including implosion physics, high-explosive performance, materials dynamics, and integrated hydro experiments (see the detailed research highlight "Proton Radiography" in Chapter 2).

The demands of the weapons program for advanced imaging technologies continue to increase. P-23 is building on its in-house capability that was developed for underground testing to meet this need. This includes the development of the GY-11 camera system, which has the capability to record up to 4000 frames per second. In addition, P-23 has investigated different technologies that will provide needed infrared cameras and pixilated detector technology for P-RAD.

Figure 2. Photograph of the Line C proton radiography system.



Accelerator Production of Tritium

P-23 contributes to the APT program by performing integral tests of the calculated neutronic performance of benchmark systems, developing beam diagnostics, and participating in irradiation studies of components for this program. Integral tests employ small-scale mockups of the accelerator target and the neutron-reflecting blanket. These allow the total neutron production, target heating, and intermediate steps to be quantified and compared with calculations. Other, advanced beam diagnostics use P-23's imaging capabilities.

Nuclear Research

As a follow-on to our work in parity violation in heavy nuclei, we are developing an experiment to measure parity violation in the np system. This experiment will attempt to measure an asymmetry of order 10^{-8} in the angular distribution of gamma rays emitted after capture of polarized neutrons by protons in a liquid-hydrogen target. A one-tenth scale experiment has been fielded at MLNSC indicating that the experimental systematic errors are indeed at the predicted low level and that a 10% measurement can be achieved (see the detailed research highlight "Measuring the Weak Nuclear Force between Protons and Neutrons" in Chapter 2). We are also working with our LANSCE colleagues to design and build a dedicated nuclear physics beam line for which the $n+p \rightarrow d+\gamma$ experiment will be the first of many.

We are also active in other tests of fundamental symmetries by observing the beta decay of trapped atoms and of free neutrons. Sensitive tests of the parity-violating beta-spin asymmetry correlation in the decay of rubidium-82 constitute one experimental sequence that we anticipate will yield results with a precision one order of magnitude greater than any previous experiment (see the detailed research highlight "Beta Decay of Rubidium-82 in a Magnetic TOP-Trap" in Chapter 2). We have observed the first parity violating beta decay asymmetry ever observed using trapped radioactive atoms. We also are designing and building an experiment to measure the asymmetry in the beta decay of polarized ultracold neutrons (UCNs) using a novel UCN source concept that has been developed at the Laboratory over the past two years.

UCNs were first produced at LANSCE in 1996 by the use of a rotor reflector. Alternative methods for producing even greater UCN densities were investigated. A cryogenic stand-alone source was built and tested in 1999 and again in 2000. The results were such that we achieved a world record 120 UCN/cm^3, three times greater than the 40 UCN/cm^3 set by Institut Laue Langevin located in Grenoble, France. Further development could provide a world-class source at LANSCE that would open up new opportunities for experiments in fundamental physics and the possibility of novel applications to materials science (see the detailed research highlight "A New Ultra-Cold Neutron Source for Fundamental Physics Measurements at LANSCE" in Chapter 2). We are also doing research and development aimed at an experiment to measure the neutron electric dipole moment (EDM) using UCNs produced and stored in a bath of superfluid helium-4. Both the EDM and the beta decay asymmetry measurements aim at detecting physics beyond the standard model of strong and electroweak interactions.

Another area of basic nuclear research is the Milagro project. Very high-energy gamma rays from the cosmos can be detected by the air shower of particles they produce when they enter the atmosphere. The Milagro project, located in the Jemez Mountains above Los Alamos, involves the operation of a high-efficiency observatory for gamma rays in the energy range around 10^{14} eV. This observatory is a joint project involving Los Alamos and a large number of universities and is sponsored by the Department of Energy (DOE) Office of Nuclear Physics, the DOE

Office of High Energy Physics, and the National Science Foundation (see the detailed research highlight "High-Energy Gamma-Astronomy with Milagro" in Chapter 2). It is well-suited for the study of episodic or transient gamma-ray sources—that is, for recording gamma-ray bursts. Milagro is operational 24 hours a day, 365 days a year, and its field of view is nearly half of the sky. Milagro was completed in 1999. The gamma-ray shadow of the moon and gamma emission from the Crab Nebula have been observed. We have also observed a possible Gamma Ray Burster with Milagro.

We are also involved in ongoing research of the properties of solar neutrinos. The number and energy spectrum of neutrinos from the sun continues to challenge our understanding of solar physics and neutrino properties. We are collaborating in the development of SNO, a neutrino observatory more than a mile underground in Sudbury, Ontario. The SNO detector became operational in 1999 and consists of an acrylic vessel holding 1,000 tons of heavy water surrounded by another vessel with 8,000 tons of light (regular) water. All three flavors of neutrinos (electron, muon, and tau) have been detected. Development of this detector includes the design and fabrication of very-low-background helium-3 detectors and new electronics. As a spin-off, the very sensitive, low-background detectors developed for the observatory will be used to screen high-density microelectronics for trace radioactive contaminants that can cause computer errors by "flipping" bit patterns. The first physics results were reported at the Neutrino 2000 Conference, and Los Alamos played a critical role in the analysis.

Applications of Basic Research

Quantum computation promises a new approach to solving some problems regarded as intractable in classical computation by using the quantum-mechanical superposition of many states (numbers) at once. To realize such a computer, we have continued our work in developing a system with cold, trapped atoms that can be put into the desired quantum-mechanical states (for more information see the research highlight "Quantum Information Science" in Chapter 2). Quantum logical operations are performed via laser manipulation of the states of the trapped atoms. Using conventional lasers, we have recently succeeded in trapping and imaging calcium ions that have the required spectroscopic structure to allow them to serve as basic quantum-mechanical bits. We have succeeded in trapping a string of 15 atoms.

Our applied research also includes work in quantum cryptography, which is covered in a detailed research highlight "Quantum Information Science" in Chapter 2. Quantum mechanics provides an approach to unbreakable cryptographic codes that not only can transmit the code "key" with security but that can also reveal the presence of eavesdropping. We hold the world record for a fiber-based quantum cryptography system and are developing longer transmission demonstrations. In a related effort, we have demonstrated transmission of a "key" through 1.65 km of air (see Figure 3). Presently we are looking towards establishing secure communications between ground-based stations and low-Earth-orbit satellites.

We have developed a novel light source for producing polarization-entangled photon pairs. These are quantum-mechanical states in which the polarization of an individual photon is random, but is nevertheless perfectly correlated with the polarization of its partner photon. This source of entanglement has allowed us to study a variety of quantum mechanical phenomena, including a world-record-setting test of quantum nonlocality, the first experimental investigation of "decoherence-free subspaces," and the first demonstration of entangled-photon quantum key distribution. In the future, we plan to develop this technology for use in the field to perform demonstrations of quantum-encrypted communications over multikilometer atmospheric paths. We also support Department of Defense (DOD) programs in mine detection and seeker applications. P-23 has developed a laser-based, range-gated imaging system for the airborne detection of submerged mines. The system has undergone testing in both controlled-tank and open-sea environments. We have supported seeker (target identification) programs with range-gated laser distancing and ranging (LADAR) experiments carried out at the Wright Laboratory's laser range at Eglin Air Force Base. These experiments are part of a joint DOE/DOD technology-development program.

Further Information

To learn more about the projects described here, as well as other projects within P-23, refer to the project descriptions in Appendix A. Some of our major achievements are also covered as research highlights in Chapter 2, as mentioned above. These include our work in quantum information, ultra-cold neutrons, fundamental symmetries with magnetically trapped rubidium-82 and the np system, neutron resonance spectroscopy, Milagro, and nuclear test data and science.

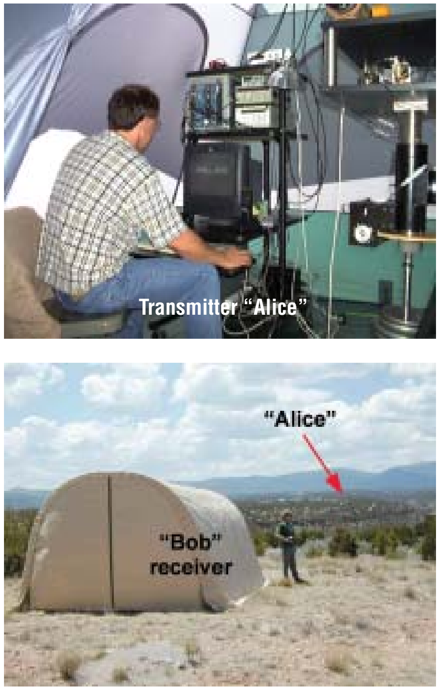


Figure 3. One of the goals of cryptography is for two parties ("Alice" and "Bob") to render their communications unintelligible to a third party. Quantum key distribution (QKD) can create "key" material whose security is assured by the laws of quantum mechanics. The "free space" quantum cryptography experiment successfully transmitted a usable cryptographic key over 1.6 km across a test range in full daylight.